CHAPTER 1

BASIC MEASUREMENTS

LEARNING OBJECTIVES

Learning objectives are stated at the beginning of each chapter. These learning objectives serve as a preview of the information you are expected to learn in the chapter. The comprehensive check questions and answers are based on the objectives and enable you to check your progress through the reading assignments. By successfully completing the OCC/ECC, you demonstrate that you have met the objectives and have learned the information. The learning objectives for this chapter are listed below.

Upon completion of this chapter, you will be able to do the following:

1. Explain the importance of performing basic electronic measurements.
2. Explain the importance of voltage measurements in troubleshooting.
3. Identify the various methods of performing voltage measurements.
4. Identify the various methods of performing current measurements.
5. Identify the various methods of performing resistance measurements.
6. Identify the various methods of performing capacitance measurements.
7. Identify the various methods of measuring inductance.

INTRODUCTION TO MEASUREMENTS

In today's modern Navy, a large part of a ship's, submarine's, or aircraft's ability to complete its mission depends on the efficiency of sophisticated electronic systems. As the technician responsible for these systems, you are the focal point in ensuring their reliability. In the event of a system failure, it is your responsibility to repair the system and to do so in a timely manner. Whether you are troubleshooting a faulty system or performing preventive maintenance, you are required to perform basic electronic measurements on a regular basis. This chapter will acquaint you with various alternative methods of performing measurements and discuss the relative merits and demerits of each method.

No discussion of electronic test equipment or electronic measurements would be complete without mentioning the Navy's Metrology Calibration (METCAL) program. Figure 1-1 shows the METCAL structure. Basically, the METCAL program is an elaborate quality control system designed to compare your electronic test equipment with test equipment of much greater accuracy. When you submit your piece of test equipment for calibration, it is compared with the calibration laboratory's equipment (referred to as STANDARDS), which are generally at least four times more accurate than yours. If your equipment does not meet specifications, it is either repaired, adjusted, or rejected with an explanation of why the calibration laboratory was unable to calibrate it. The accuracy of equipment at your local calibration laboratory is ensured by calibration of the test equipment to the standards of the next higher echelon calibration laboratory. The accuracies of test equipment at each higher echelon is increased by a ratio of approximately 4 to 1.

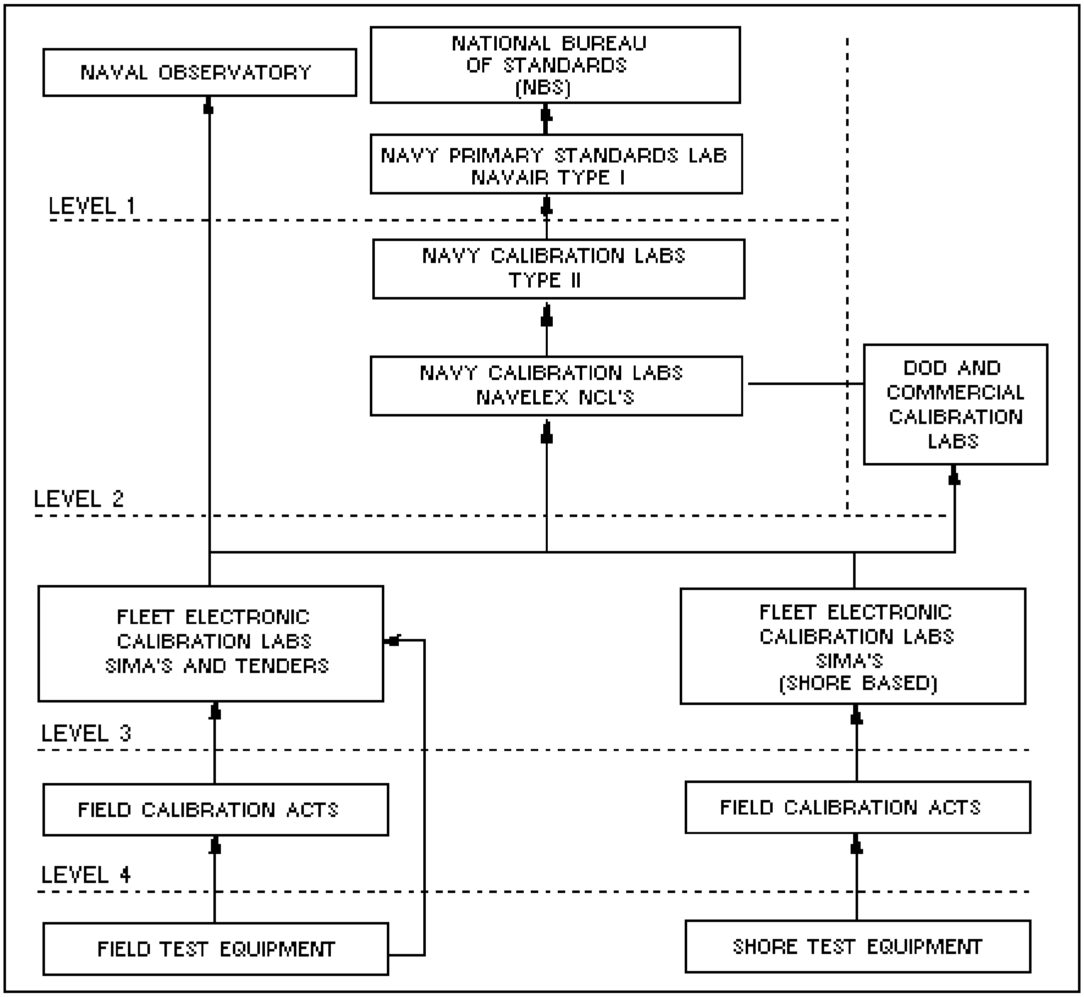


Figure 1-1.—Calibration laboratory structure.

METCAL provides assurance that your test equipment is in top-notch shape. Remember, your measurements are only as accurate as your test equipment; be fully aware of the limitations of your test equipment and never use equipment that isn't properly calibrated when performing measurements or adjustments.

Q-1. What assures the accuracy of your electronic test equipment?

Now that we have discussed the advantages of calibrated test equipment, let's review the reason for all this concern. The fundamental electrical quantities of a circuit are voltage and current and are dependent on the circuit characteristics of resistance, capacitance, and inductance. In addition to these three individual characteristics, don't forget that many electronic components exhibit more than one circuit characteristic at the same time. An example would be a piece of coaxial cable that is engineered by its manufacturer to meet characteristic specifications for impedance, capacitance, and inductance. But let's keep it simple and begin by covering voltage measurements.

Operation and use of common test equipment was covered in NEETS Module 16, *Introduction to Test Equipment,* NAVEDTRA B72-16-00-95. It is recommended that you review this module before continuing.

VOLTAGE MEASUREMENTS

Most Navy technical manuals provide voltage charts that list correct voltages at all primary test points in a piece of equipment. Voltage measurements, when compared with these charts, provide a valuable aid in locating troubles quickly and easily. However, if the sensitivity of the test equipment differs from that of the test equipment used in preparing the chart, the voltage measurements may not reflect true circuit conditions. You must keep in mind that a voltmeter with low sensitivity used on a low range may disturb circuits under test or provide a false indication. Most technical manuals will tell you what type and model of test equipment was used to prepare the voltage charts. As a rule of thumb, the input impedance of the voltmeter should exceed the impedance of the circuit by a ratio of at least 10 to 1. Technicians have spent uncounted hours of wasted time because they have selected improper test equipment.

Q-2. The input impedance of your test equipment should exceed the impedance of the circuit under test by what ratio?

DC VOLTAGE MEASUREMENTS

Direct current voltage may be steady, pulsating, or have ac superimposed on it. The average value of a dc waveform depends on the symmetry of the wave and other aspects of the wave shape. It can vary from 63.6% of peak value for a rectified full sine wave to 50% of peak value for a triangular wave. For a superimposed sine wave, the average value can be zero. Regardless of whether the dc is steady, pulsating, or the ac is superimposed on the dc, a rectifier form of measuring device will indicate its *average value*.

Voltages are usually measured by placing the measuring device in parallel with the component or circuit (load) to be measured. The measuring device should have an infinite internal resistance (input impedance) so that it will absorb *no* energy from the circuit under test and, therefore, measure the true voltage. The accuracy of the voltage measurement depends on the total resistance of the measuring device compared to the load being measured. When the input impedance of the measuring device is 10 times greater than the load being measured, the error usually can be tolerated. If this error cannot be tolerated, a high input impedance measuring device, such as a vacuum tube voltmeter (vtvm), should be used. Alternatively, using two voltmeters in series increases the voltage range and, because of the increase in total voltmeter resistance, provides a more accurate measurement of voltage across the load. If the voltage to be measured is sufficiently high, more than two similar voltmeters can be connected in series across the load to provide greater accuracy; the total voltage measurement is the sum of the individual meter indications.

Q-3. What are the advantages of using two voltmeters in series?

Multimeter Method

A common piece of test equipment used in the Navy is the Simpson 260 analog multimeter, as shown in figure 1-2. It is capable of measuring both ac and dc voltages of up to 5,000 volts.

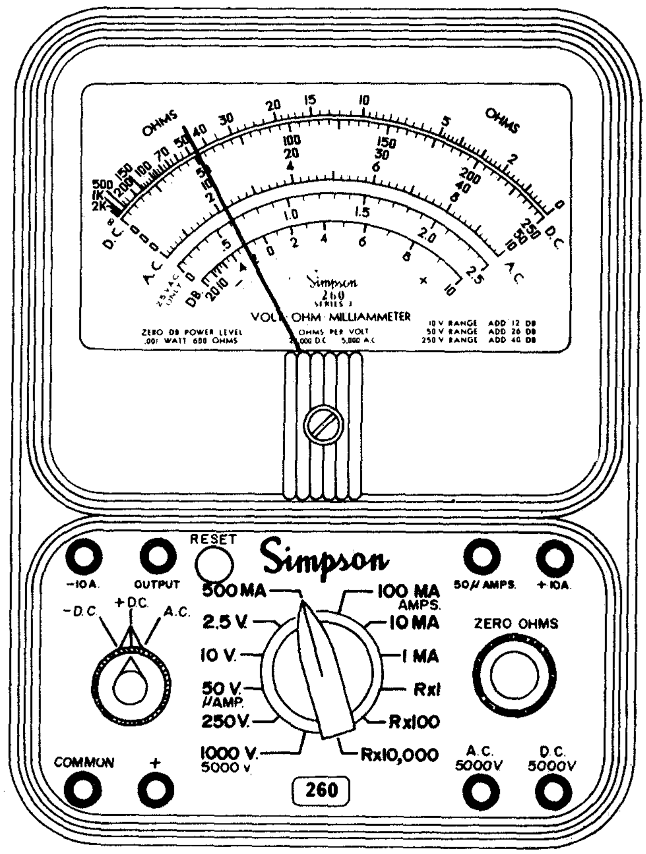


Figure 1-2.—Simpson 260 multimeter.

Two obvious advantages of the Simpson 260 are its portability and ease of operation. Among its disadvantages are its low input impedance and the inherent low accuracy associated with D'Arsonval meter movements, which are used in the meter. When performing measurements with any analog multimeter, remember that the most accurate readings are taken with the pointer midscale. You should also be aware of inaccuracies introduced as a result of parallax. PARALLAX is defined as the apparent displacement of the position of an object because of the difference between two points of view. In the case of meters, this means the position of a meter's pointer will appear to be at different positions on the scale depending on the angle from which the meter is viewed. Some of the Simpson 260 and 270 series multimeters have effectively eliminated the problem of parallax by incorporating a mirror on the scale that accurately reflects the position of the pointer of the meter movement.

Q-4. At what point on a meter movement are the most accurate readings taken?

Oscilloscope Method

A dc voltage measurement can be made with an oscilloscope, as shown in figure 1-3, that has a direct-coupled deflection amplifier or terminals for connection directly to the deflection plates of the cathode-ray tube. Measuring a dc voltage with an oscilloscope is convenient only under certain circumstances; for example, when other measurements are being made on the same equipment with the oscilloscope or when a vacuum tube voltmeter is not available and a high-impedance measuring device is required.

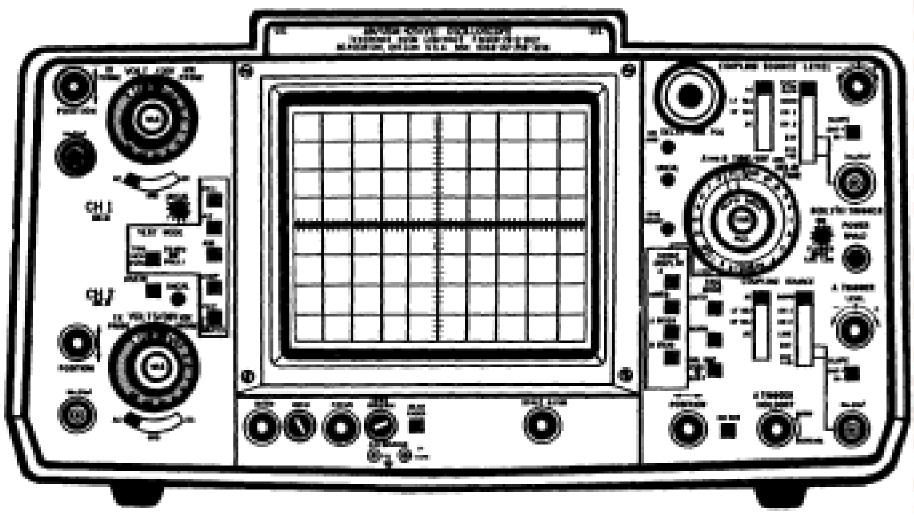


Figure 1-3.—Dual-trace oscilloscope.

Oscilloscopes have a high input impedance and normally will not load down the circuit under test. However, oscilloscopes are primarily designed for waveform observation and are typically less accurate than other pieces of test equipment used to measure dc voltages. A distinct advantage of the oscilloscope is its ability to monitor the level of ac ripple voltage riding the dc voltage. This feature makes the oscilloscope an indispensable aid in troubleshooting dc power supplies with excessive ripple caused by component failure.

Digital Multimeter Method

Most analog voltmeters (that use D'Arsonval meter movements) in common use today are accurate to approximately ±2% of full-scale reading. Most digital multimeters, as shown in figure 1-4, have a high input impedance and are not likely to disturb the circuit being tested. The digital multimeter in most cases provides an accuracy of at least ±0.1%.

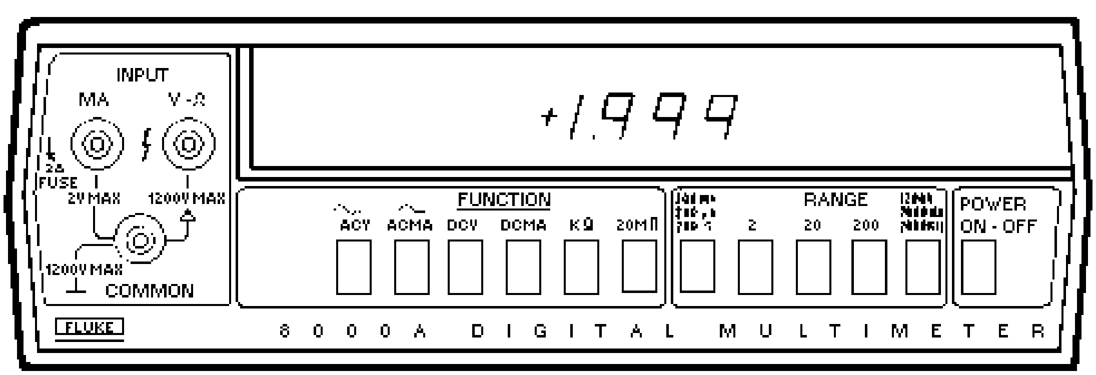


Figure 1-4.—Digital multimeter.

Digital multimeters display the reading numerically. These direct-reading displays, along with automatic range- and polarity-changing features, eliminate the problem of parallax, reduce error and tedium, and increase measurement speed. Data from these meters in digital format can also be processed by computers, printers, tape and card punches, and magnetic-tape equipment. Digital multimeters are typically compact and lightweight; many come with rechargeable batteries, making them ideal for portable field use. The disadvantages are that they are not rugged and will not tolerate abuse and that some models do not produce sufficient bias voltage to test a diode or transistor junction. The John Fluke Model 77 A/N digital multimeter is presently being purchased by the Navy and will eventually phase out the older and less accurate analog meters.

Differential Voltmeter Method

Using the differential voltmeter, as shown in figure 1-5, provides one of the most accurate methods of measuring dc voltage. Typical accuracies attained by this method are ±0.005%. These extremely high accuracies are achieved by the design of the voltmeter with precision internal reference voltages and precision resistors. As discussed earlier in NEETS, module 6, *Introduction to Electronic Emission, Tubes, and Power Supplies*, most differential voltmeters can be operated as transistor voltmeters (tvm) or as differential null voltmeters. The tvm mode is used to measure the *approximate* voltage and polarity of the unknown voltage being measured. The approximate voltage, as measured in the tvm mode, is then used to make the initial range and mode switch selections for nulling the input voltage.

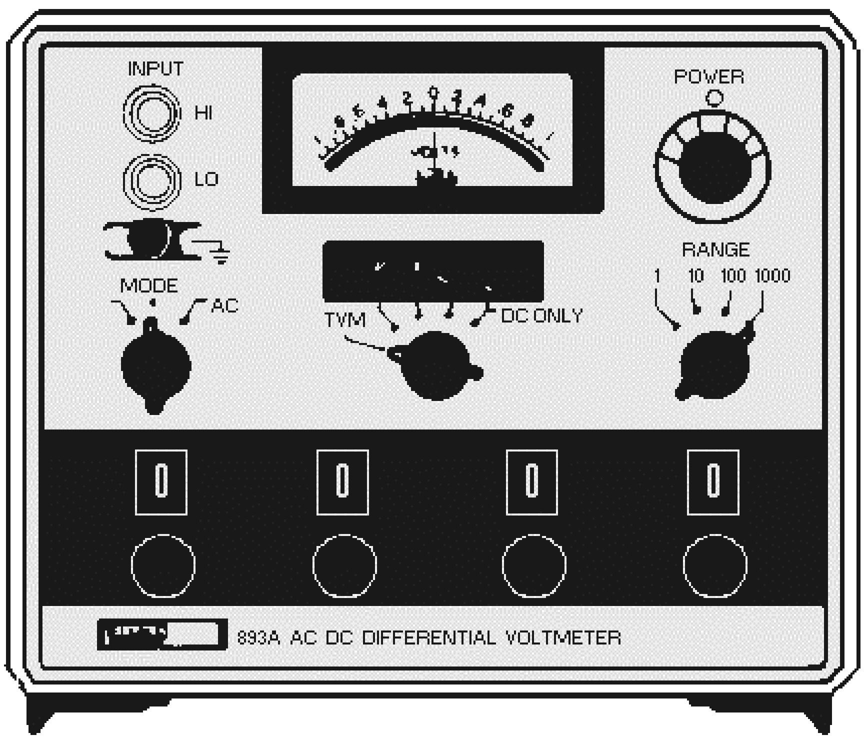


Figure 1-5.—Ac-dc differential voltmeter.

The advantages of using a differential voltmeter for measuring dc voltages are the extreme accuracy and minimal circuit loading made possible by the high input impedance of the meter. However, differential voltmeters are less portable, heavier, and require greater skill and time when performing measurements than other types of voltmeters. Additionally, they require long warm-up periods and are susceptible to variations in temperature and humidity.

Q-5. What are the advantages of using a differential voltmeter?

AC VOLTAGE MEASUREMENTS

When ac voltage measurements are performed, the input impedance of the selected test equipment determines the amount of energy removed from the circuit under test. If an ac meter is placed across a high-impedance circuit, the meter may load the high-impedance circuit and disturb circuit conditions, possibly to the point of causing the circuit to cease functioning. A dc electronic voltmeter, used in conjunction with a rectifying probe, extracts only a small amount of energy from the circuit under test. Another advantage of an electronic voltmeter over the analog voltmeter is that voltages of low values can be accurately measured.

If the circuit being measured is a relatively high-frequency circuit, the internal capacitance of an analog voltmeter rectifier could produce a disturbance by detuning the circuit. Figure 1-6 depicts the frequency response of a Simpson 260. Note the percent of error introduced at different frequencies. For high-frequency voltage measurements, an electronic voltmeter or an oscilloscope should be used. The sensitivity of the meter (or oscilloscope) determines the lowest voltage it can measure accurately, and the shunt capacitance of its input determines the upper frequency limits. It should be clear that the frequency response of a piece of test equipment is just as important as its range limitations. If you exceed the *range limitations* of a meter, it will either "peg" the meter or belch out the smell of smoke that many of us are intimately acquainted with. This, however, is not the case when you exceed the *frequency limitations* of your test equipment. Your test equipment will normally show a response, but that response will be grossly inaccurate. The lesson to be learned here is that you should be fully aware of the limitations of your test equipment and adhere to them.

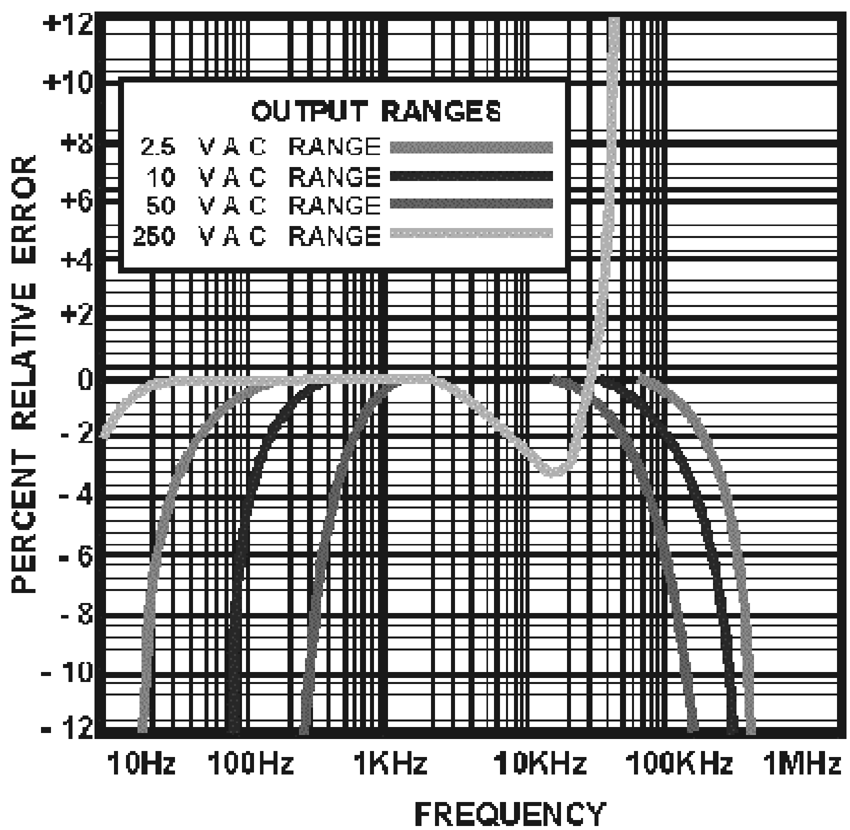


Figure 1-6.—Simpson 260 frequency response for ac voltage ranges.

Q-6. The frequency response of test equipment refers to what aspect of ac voltage measurements?

Multimeter Method

As previously stated, an analog multimeter's usefulness is limited by its low input impedance and poor accuracy (typically ±2%). However, rugged construction and ease of operation make analog multimeters extremely useful whenever poor accuracy and low input impedance can be tolerated. When performing ac voltage measurements with a multimeter, be certain that the frequency of the signal being measured falls within the upper and lower frequency limitations of the meter.

Oscilloscope Method

A major advantage of using an oscilloscope for ac voltage measurements is that the waveform can be observed; consequently, errors in measuring complex peak voltages are minimized. An oscilloscope may be used as a high-impedance ac voltmeter. In standard oscilloscopes, the vertical amplifier input impedance is generally greater than 1 megohm, making it possible to measure voltages in high-impedance circuits. If the signal is applied directly to the plates, rather than at the vertical amplifier input, the input impedance is increased considerably.

Voltage measurements are most easily made when the deflection of the trace extends across the major portion of the oscilloscope screen; whenever possible, the trace should cover at least 60% of the vertical viewing area of the screen. If the amplitude of the measured voltage is very low, the trace dimensions may be small. If a voltage to be measured is large and cannot be attenuated to a usable value by attenuation circuits within the oscilloscope, an external resistive or capacitive voltage divider can be used. Such voltage dividers are often furnished with oscilloscope test sets and are called HIGH VOLTAGE PROBES. When the voltage of pulses or other complete waveforms is being measured, the high voltage probe selected must be so designed as not to distort the measured signal. Most probes have adjustable (compensating) capacitors that are used to adjust the symmetry of the displayed waveform. You adjust the probe by monitoring either the calibrator output of the oscilloscope or a known good signal and adjusting the probe for a symmetrical display. Oscilloscopes are calibrated to display peak-to-peak values. To determine the rms voltage of a sinusoidal signal, divide the number of graticule units from the positive to the negative peaks by two and multiply this value by 0.707. When using the oscilloscope for ac voltage measurements, ensure the upper frequency range of the oscilloscope is not exceeded; otherwise, inaccurate values will be displayed. Most commonly used oscilloscopes have a frequency response from dc up to 100 megahertz.

Q-7. Ideally, an oscilloscope presentation should cover what vertical portion of the screen?

Digital Multimeter Method

As previously mentioned, digital multimeters present a high input impedance to the circuit under test and are fairly accurate. Many earlier models had very limited frequency responses. Even today the upper frequency limitations of digital multimeters vary from 20 kilohertz to over 300 kilohertz, depending on the model. Their upper frequency limitations can, however, be significantly extended by using optional rf probes. When you perform ac voltage measurements with a digital multimeter, remember that they are *true rms* indicating devices.

Differential Voltmeter Method

Most differential voltmeters can be used to measure both ac and dc voltages. The differential voltmeter method of measuring ac voltage is the most accurate of the common measurement techniques. Typical accuracies are ±0.05% when operated in the ac mode.

CURRENT MEASUREMENTS

Unless an ammeter is already an integral part of the circuit under test, current measurements are rarely taken. In the case of a high-resistance circuit, it will contain such a small amount of current that it cannot be measured accurately with ordinary field test equipment. In lower resistance circuits, current measurements can be taken only if the ammeter is placed in series with the circuit under test. These measurements require that a circuit connection be unsoldered or otherwise opened to insert the meter in series with the circuit. An easier method you may use to obtain a current measurement is to take a voltage measurement across a known resistance and calculate the current with Ohm's law. The accuracy of current measurements depends on the internal resistance of the meter as compared with the resistance of the external circuit. If the total circuit current is decreased by increasing the load, then the percentage of error will decrease. Therefore, greater accuracy is obtained if the meter resistance is considerably less than the load resistance. A method of obtaining greater accuracy of current measurement is to decrease the total internal meter resistance with respect to load resistance. This is accomplished by connecting two ammeters in parallel with each other and in series with the circuit in which the current is being measured. Additional ammeters may be connected in parallel in the same manner for increased accuracy. This method also increases the range of measurements that can be taken. The arithmetical sum of the indications of all the parallel meters represents the total current flow in the circuit. You should note that this is not a common test method and that your test equipment may be damaged if connected incorrectly.

MULTIMETER METHOD

As previously mentioned, current measurements are usually taken by breaking the current path of the circuit under test and electrically inserting a meter in series. This is normally accomplished by disconnecting a wire from a terminal or unsoldering one end of a component and electrically inserting the meter in series using the meter leads. This method is both time consuming and usually requires the use of a soldering iron, which can damage components. Most analog multimeters cannot be used for measuring ac current and are only accurate to within ±2% on dc ranges.

Q-8. What are the advantages of connecting ammeters in parallel when performing current measurements?

DIGITAL MULTIMETER METHOD

Unlike the analog multimeter, the digital multimeter will measure ac current as well as dc current. Again, current measurements are taken by breaking the current path and inserting the meter in series. Regardless of whether you're using an analog multimeter or digital multimeter, this procedure for measuring current is time consuming. However, there is a major advantage to be gained by using the digital multimeter — its high degree of accuracy. The Fluke 8000A digital multimeter, for example, is accurate to within ±0.3% when measuring dc current and ±1% when measuring ac current. These accuracies are representative of most medium-priced digital multimeters.

CURRENT TRACERS

For the purpose of discussion, we have selected the Hewlett-Packard 547A, shown in figure 1-7, as a representative current tracer. A current tracer will not actually measure current; it is designed to indicate the presence of current and the relative magnitude of one source of current as compared to another. The Hewlett-Packard 547A is a hand-held probe that enables you to precisely localize low-impedance faults in a circuit. The probe senses the magnetic field generated by a pulsing current and lights an indicator lamp near the current tracer tip. The brightness of the indicator lamp is proportional to the magnitude of the current. The sensitivity of the indicator lamp can be adjusted with a thumb-wheel potentiometer located on the probe. Figure 1-8 depicts a typical logic circuit application for a current tracer. Current tracers are ideally suited for locating shorted or opened printed-circuit-board runs, wires, or components. In the absence of a suitable pulsing current to drive the current tracer, a logic pulser or pulse generator may be used as a signal source. The inherent disadvantage of a current tracer is that it requires an external power supply. They can, however, be connected to the power supply of the equipment under test if the voltage is correct.

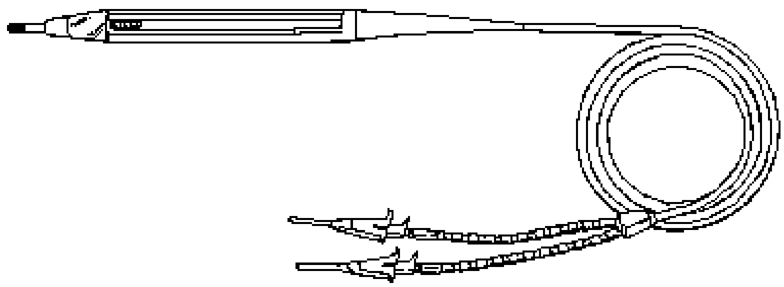


Figure 1-7.—Current tracer.

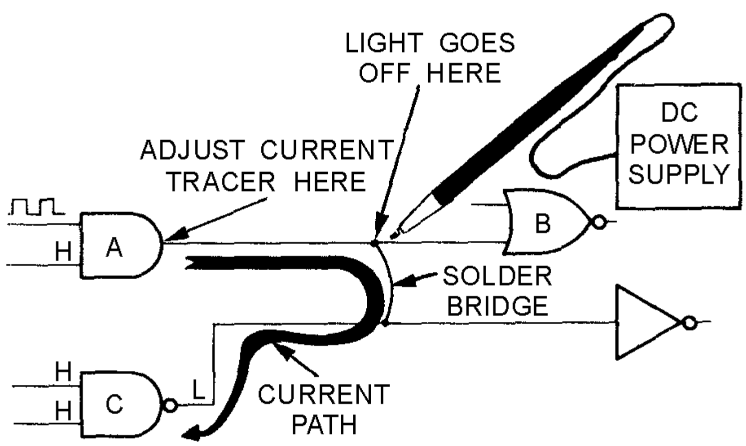


Figure 1-8.—Current tracer application.

CURRENT PROBES

Current probes, as shown in figure 1-9, are primarily designed to be used with an oscilloscope or milliammeter for measuring current. Although not used very often by Navy technicians, current probes are available. The primary advantage in using a current probe is that it does not need to be in series with the current being measured. Unsoldering wires or connections to terminals is not necessary; current probes are designed to be clamped onto insulated conductors. They are able to sense, through inductive action, the magnitude of the current flowing in the conductor. Current probes are designed for performing small ac current measurements. Also, when you use them in conjunction with current probe amplifiers, the capabilities of the current probe are extended to measurement of both ac and dc currents with large magnitudes. Current probes are extremely useful when you measure the current drain on a power supply, start-up current of a motor, or current flow in relays. These probes can be divided into three basic types: passive, active, and Hall effect. Each type has advantages and disadvantages peculiar to its method of operation. Prior to using a current probe, you should thoroughly understand its instructions.

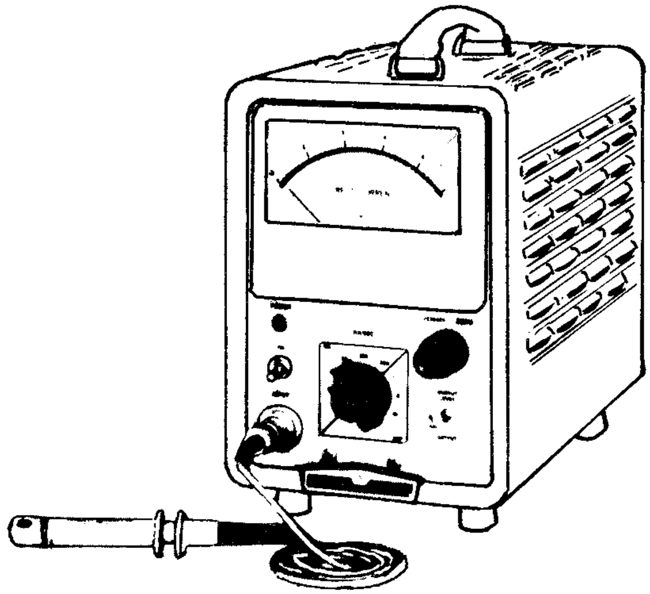


Figure 1-9.—Current probe used with electronic ammeter.

Q-9. What is the primary advantage of using a current probe?

OSCILLOSCOPE METHOD

Current can be measured with an oscilloscope by shunting the input terminals with a low-value resistor. The input terminals must then be connected in series with the circuit being tested. The value of the resistor must be small enough not to interfere with the operation of the circuit under test. At the same time, it must be large enough that the voltage developed will cause adequate deflection of the oscilloscope trace. For example, if an oscilloscope with a vertical deflection sensitivity of 0.1volt rms per centimeter (cm) is used in conjunction with a 10-ohm shunt resistor to measure a 25-milliamp current, the vertical trace will be deflected 2.5 centimeters, as shown in the following example:

Where:

$$I = 25 \text{ mA}$$

$$R = 10 \text{ ohms}$$

$$\text{Sensitivity} = 0.1 \text{ volt/cm}$$

First we'll figure the applied voltage:

$$E = IR$$

$$E = 0.025 \text{ A} \times 10 \text{ ohms} = 0.25 \text{ volts}$$

Now let's figure the deflection in cm:

$$\text{Deflection} = \frac{\text{voltage applied}}{\text{sencitivity}}$$

$$\text{Deflection} = \frac{0.25 \text{ volt}}{0.1 \text{ volt/cm}} = 2.5 \text{ cm}$$

For current measurements the oscilloscope can be calibrated by connecting an ammeter in series with the input terminals and the calibration signal source. An alternate method is to determine the value of the shunt resistor and measure the calibration signal voltage developed across it with an accurate voltmeter. The calibration signal current can then be calculated by means of Ohm's law. Since the oscilloscope merely indicates the voltage developed across the shunt resistor, the measurements for alternating or direct current will be similar to voltage measurements using an oscilloscope.

RESISTANCE MEASUREMENTS

A high percentage of technical manuals contain point-to-point resistance charts that list correct resistance readings for major test points. These resistance charts are extremely useful when you troubleshoot faulty equipment. Without them, equipment resistance measurements within a complicated circuit would not mean much. Many circuits contain other circuit elements, such as capacitors, coils, or other resistors in parallel with the resistances being measured. This, of course, is a possible source of measurement error that you eliminate when you disconnect or unsolder one side of the resistor or a group of resistors under test.

You should be thoroughly familiar with the calibration of your ohmmeter. Analog meters are typically more accurate and easier to read at midscale. With the exception of bridge circuits, a meter may provide only approximate resistance readings. However, these readings may be adequate when you also consider the wide tolerances of resistors themselves. An ohmmeter that you use in field testing should be portable, convenient, and simple to operate - factors that usually are more important than extreme accuracy.

When an ohmmeter is used, completely de-energize the circuit under test and remove any current-sensitive elements before the resistance measurement is performed. Low-resistance measurements that require precision readings should be taken with a bridge type of instrument.

An ohmmeter consists of a galvanometer, batteries, and resistors of known value that are connected in such a way that unknown resistors to be measured are compared with standard values. Figure 1-10 illustrates three basic ohmmeter circuits: (A) single range type, (B) series multirange type, and (C) shunt type.

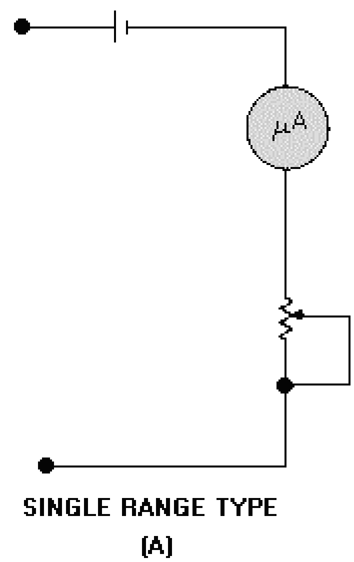


Figure 1-10A.—Basic ohmmeter circuits.

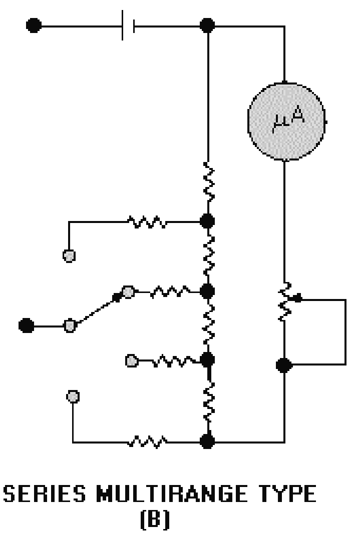


Figure 1-10B.—Basic ohmmeter circuits.

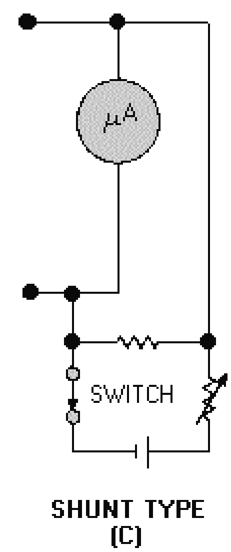


Figure 1-10C.—Basic ohmmeter circuits.

MULTIMETER METHOD

When you use an analog multimeter to perform resistance measurements, the first thing you do is zero the meter. The meter indication varies greatly depending on the resistance of the test leads, the condition of the batteries within the meter, and the resistance range selected on the multimeter. The meter should be zeroed every time you change range settings. To zero a multimeter you short the leads together and adjust the meter for a full-scale deflection. Scale markings are spaced closer together toward the infinity point on the meter; therefore, more accurate readings are obtained near center scale. You should select a range setting that will give you a mid-scale indication.

Ohmmeter applications include resistance measurements; continuity checks; and inductor, capacitor, and transformer checks. A transformer, for example, may be tested by checking whether there is an open or short, low-insulation resistance to ground, or improper continuity between transformer windings. A capacitor may be tested to determine whether it is open or shorted. Ensure that capacitors are properly discharged before you test them; otherwise, damage to the multimeter may occur. When an ohmmeter is placed in series with a capacitor, the changing current will cause a meter deflection that is proportional to the capacitance. The deflection obtained is compared with the deflection from a similar capacitor of known value. This deflection may be small or large, depending on the type and size of the capacitor and the voltage of the battery within the meter. An external series battery will increase the sensitivity of the instrument.

Q-10. How do you compensate for the resistance of the test leads of a meter?

DIGITAL MULTIMETER

The two major advantages of using a digital multimeter are its ease of operation and accuracy. Most digital multimeters can be ordered with an optional battery pack, which makes them just as portable as an analog multimeter. Another advantage is that their LED or LCD readouts are much easier to read than the scale on an analog multimeter. Digital multimeters also are ideally suited for measuring sensitive devices that might otherwise be damaged by the excessive current associated with analog multimeters — maximum current flow through the component being tested is typically limited to less than 1 milliamp. When measuring small values of resistances, remember to consider the resistance of your test leads. Most digital multimeters cannot be zeroed in the way analog multimeters can. With digital multimeters, you have to short the leads, read the lead resistance displayed, and then subtract the reading from subsequent component measurements that you make.

Q-11. Why are digital multimeters well suited for testing sensitive devices?

RCL BRIDGES

The 250DE+1325 is a typical resistance, capacitance, inductance (rcl) bridge. Like the vtvm, the rcl bridge has several disadvantages. It requires ac power and a lengthy warm-up period, and its accuracy is limited to ±2%. The rcl bridge uses a tuning indicator electron tube, commonly referred to as the bridge's "eye," and an internal arrangement of resistors that form a Wheatstone bridge. As discussed in NEETS, module 16, the rcl bridge can be a time-consuming method of performing resistance measurements.

Difficulty may be experienced when you attempt to measure wire-wound resistors. To obtain a sharp balance on the indicator, you can shunt the resistor with a variable capacitor and adjust the capacitor for the clearest indication. The resistance measurement will not be affected by this reactance neutralization.

MEGGERS

Meggers produce the large voltages that are required to measure resistances as high as 10,000 megohms — only high resistance values can be measured. The unknown resistance is connected between the megger terminals, and the hand generator part of the meter is cranked. Some meggers are capable of producing in excess of 500 volts, so use caution when you operate them. Typical applications for a megger are testing unterminated transmission lines and ac power cords for insulation breakdown.

DIFFERENTIAL VOLTMETERS

It is a seldom-known fact that the Fluke 893 ac-dc differential voltmeter can be used for measuring extremely high resistances from 10 megohms to 10^6 megohms with a typical accuracy of ±5%. This measurement method, however, requires some basic calculations on your part. The obvious advantage of the differential voltmeter is its capability of measuring extremely high resistances. Consult the Fluke 893 technical manual for initial switch settings and a more detailed explanation of its operation.

CAPACITOR MEASUREMENTS

Capacitance is that property of a circuit that produces an electrostatic field when two conducting bodies separated by a dielectric material have a potential applied to them. Capacitors are made by compressing an insulating material (dielectric) between two conductors (plates). The farad is the basic measurement of capacitance. It is dependent upon the area of the plates, the distance between the plates, and the type of dielectric used. Electrically, the farad is a measure of 1 coulomb of potential charged by 1 volt. A coulomb (the amount of current flow maintained at 1 ampere that passes a given point of a circuit in 1 second) is a large charge. Most capacitors are measured in millionths of a farad (microfarad), expressed as ∝F, or in one-millionth of a microfarad (picofarad), expressed as pF.

Capacitors incur various losses as a result of such factors as resistance in the conductors (plates) or leads, current leakage, and dielectric absorption, all of which affect the power factor of the capacitor. Theoretically, the power factor of an ideal capacitor should be zero; however, the losses listed above cause the power factors of practical capacitors to range from near 0 to a possible 100%. The average power factor for good capacitors, excluding electrolytics, is 2% to 3%. Current leakage, which is an inverse function of frequency, is important only at the lower frequencies and becomes negligible at higher frequencies. Dielectric absorption (sometimes referred to as dielectric viscosity) results in losses that produce heat. The effect of this type of loss is the same as resistance in series with the capacitor.

You have probably learned the hard way that some capacitors can retain a charge long after the voltage has been removed. The electrical charge retained by capacitors in de-energized electronic circuits is, in many cases, sufficient to cause a lethal shock. Be sure you and those working with you consider this hazard before performing any type of maintenance on any electrical or electronic circuit and before making connections to a seemingly dead circuit. Use extreme caution prior to working on or near de-energized circuits that employ large capacitors. Be safe—discharge and ground all high-voltage capacitors and exposed high-voltage terminal leads by using only an authorized shorting probe, as shown in figure 1-11. Repeat discharge operations several times to make sure that all high-voltage terminations are completely discharged. It is of the utmost importance that you use only an *authorized* safety shorting probe to discharge the circuits before performing any work on them. An authorized *general-purpose* safety shorting probe for naval service application may be requisitioned using the current stock number listed in the ELECTRONICS INSTALLATION AND MAINTENANCE BOOK (EIBM), *General* NAVSEA 0967-LP-000-0100, Section 3, Safety Equipment. Certain electronic equipment are provided with built-in, special-purpose safety shorting probes. These probes are *not* considered general purpose. Use them only with the equipment for which they are provided and only in a manner specified by the technical manuals for the equipment. It is considered to be poor practice to remove them for use elsewhere.

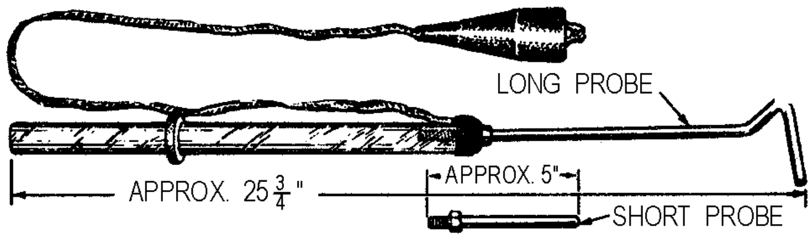


Figure 1-11.—Safety shorting probe.

When using the general-purpose safety shorting probe, always be sure first to connect the grounding clip to a good ground connection (if necessary, scrape the paint off the grounding metal to make a good contact — paint can be replaced, lives can't). Then, while holding the safety shorting probe by the handle behind the protective shield, touch the end of the metal rod to the points to be discharged. Touch each point several times to ensure that the circuit is completely discharged. Be extremely careful that *you* do not touch any of the metal parts of the safety shorting probe while touching the probe to the exposed "hot" terminal. Don't develop a nonchalant or routine attitude about these procedures. It pays to be safe; use the safety shorting probe with care.

Large capacitors, dormant in storage, can also develop a large static charge. This charge is caused by environmental conditions such as a close proximity to an rf field. An easy way to avoid this condition is to short the stored capacitor's terminals with a piece of wire before putting it in storage. Remember to remove the wire before installing the capacitor. If you receive a large capacitor that is not shorted, short the terminals together. Remember, CHARGED CAPACITORS CAN KILL.

Q-12. Charged capacitors can kill. True or false?

BRIDGE-TYPE MEASUREMENTS

Capacitor tests involving quality and value must be made in the course of everyday troubleshooting. You must make the important decision of whether to reject or continue to use a certain capacitor after it has been tested. Capacitance measurements are usually accomplished by either a bridge-type or a reactance-type capacitance meter. The bridge-type capacitance meter is much more accurate than the reactance-type meter. You may want to review rcl bridges in chapter 1 of NEETS, module 16, before reading further. Capacitance tolerances vary more widely than resistance tolerances and are dependent upon the type of capacitor, the capacitance value, and the voltage rating. The results of capacitance tests must be evaluated to determine whether a particular capacitor will fulfill the requirements of the circuit in which it is used.

The power factor of a capacitor is important because it is an indication of the various losses attributable to the dielectric, such as current leakage and dielectric absorption. Current leakage is of considerable importance, especially in electrolytic capacitors.

Figure 1-12 is a simplified schematic of a capacitance bridge. As you can see, a capacitance bridge is very similar in construction to a resistance bridge with the exception of the standard capacitor (C_S) and the unknown capacitor (C_X). Because current varies inversely with resistance and directly with capacitance, an inverse proportion exists between the four arms of the bridge. The following expression shows the inverse proportion between resistors A and B and capacitors C_S and C_X:

$$\frac{A}{B} = \frac{C_X}{C_S}$$

Solving for C_X :

$$C_X = \frac{AC_S}{B}$$

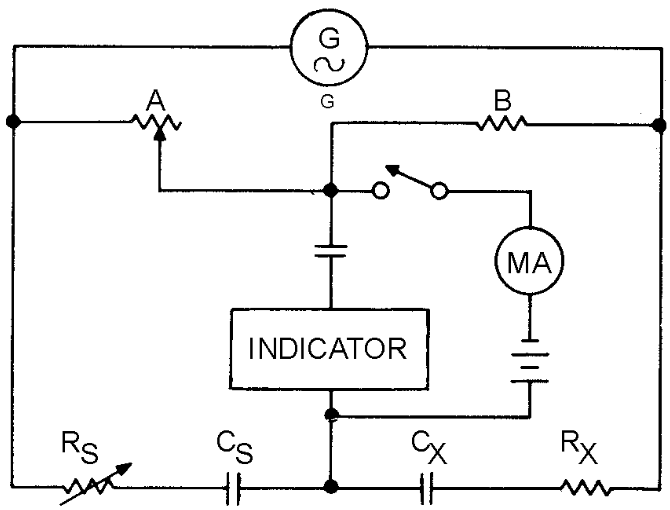


Figure 1-12.—Simplified capacitance bridge.

It is actually the capacitive reactance, rather than the capacitance, that is balanced in this circuit.

In addition to its reactive properties, the capacitor under test always exhibits some loss. This loss may have the characteristics of either a shunt or series resistance, or it may be a combination of both. Regardless of its true nature, the loss can always be represented as a simple series resistance, which is shown in figure 1-12 as R_X. This loss is balanced by the calibrated resistor R_S. Rather than calibrate this control in terms of resistance, it is convenient to calibrate it in terms of the dissipation factor (the ratio of the energy dissipated to the energy stored in a capacitor). The R_S control then provides the means for completing the capacitance balance, and its dial reading indicates a loss figure for the capacitor under test.

Q-13. Which is more accurate, the bridge- or reactance-type meter?

REACTANCE-TYPE MEASUREMENTS

The reactance type of capacitance measuring equipment makes use of the following principle: If an ac voltage (usually 6.3 volts) at a fixed frequency is applied across a capacitor and resistor in series, the voltage drop produced across the reactance of the capacitor by the resulting current flow is inversely proportional to the capacitance. The voltage drop is used to actuate a meter that is calibrated in capacitance values. This test equipment gives approximate values only and, like the ohmmeter, is used mostly when portability and speed are more important than precision. The accuracy of the reactance-type measurement is less for capacitors that have a high power factor. In capacitors with high power factors, the losses incurred effectively place a certain amount of resistance in series with the capacitive reactance. The effect of this resistance, when the capacitor is measured, is to cause a greater voltage drop across the capacitor. This drop is not because of the reactance above, but is the result of the impedance, which of course is made up of both the reactance and the resistance. Therefore, the capacitance indicated by the analyzer will be lower than the actual value.

Figure 1-13 shows a simplified schematic diagram of the capacitance-measuring section of a typical reactance-type electronic volt-ohm-capacitance milliammeter. A 6.3-vac voltage is taken from the filament source and applied across the resistive voltage divider network to determine the designated value of the capacitor. Because of a particular use or circuit application, some capacitors are permitted an even wider variation of capacitance value than is indicated by their rated tolerances.

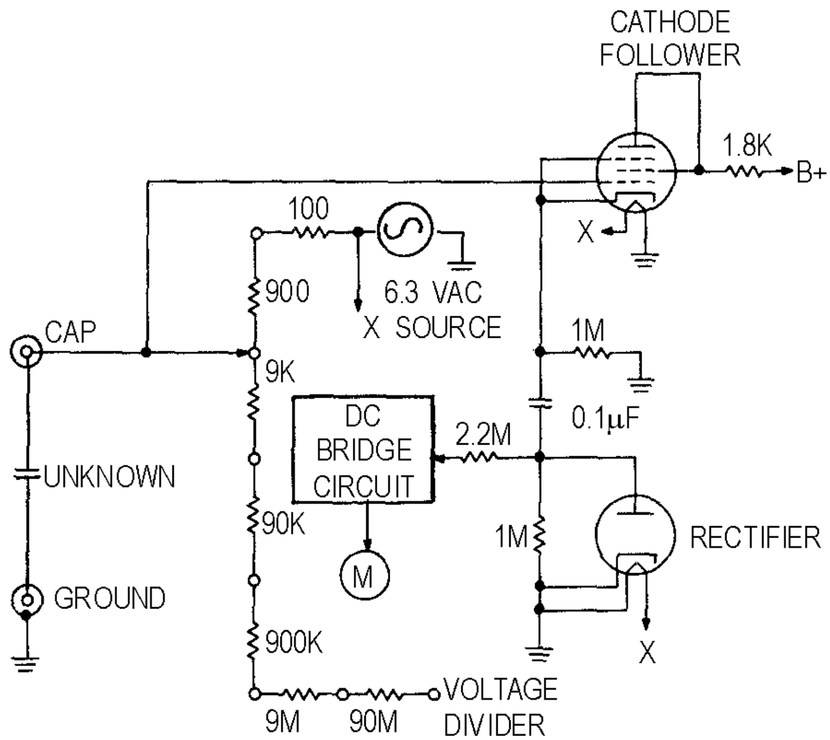


Figure 1-13.—Reactance-type capacitance meter.

INDUCTANCE MEASUREMENT

A current flowing through a conductor produces a magnetic field around that conductor. If the conductor is formed into a coil, a stronger magnetic field is set up. The relationship between the strength of the field and the intensity of the current causing it is expressed by the inductance of the coil (or conductor). When the current producing the magnetic field ceases, the energy of the magnetic field is returned in part to the circuit source in the form of a reverse current. Inductance, then, is the ability of a coil to function as a storehouse of energy in magnetic form and is determined by the shape and dimensions of the coil. Inductance is measured in henries, millihenries, or microhenries. Inductors can be described generally as circuit elements used to introduce inductive reactance into ac circuits.

An inductor is essentially a coil of wire wound around a form using a core of air, magnetic metal, or nonmagnetic metal. A core of magnetic metal produces greater inductance (for a coil of given size and number of turns) than does an air core; a core of nonmagnetic metal produces less inductance than does an air core. At frequencies in the hf and higher regions of the frequency spectrum, coils of small size and high *Q* (discussed briefly at the end of this section) are generally required. These coils usually are single-layered with air or metallic cores. Since comparatively low values of inductance are required, this type of coil is very compact, and relatively high values of *Q* are obtained.

At frequencies in the lf and mf regions of the frequency spectrum, single-layered, universal, spiral, and other types of windings are used. When size is a factor, the more compact windings are preferred to the single-layered type of coil. At frequencies below 500 kilohertz, the single-layered type is too large for practical use; therefore, the more compact types are used exclusively.

The inherent resistance of the conductor with which an inductor is wound is the most important factor contributing to the losses of the inductor. Losses caused by this resistance increase with frequency. This results in a concentration of current near the outer surface of the wire, called SKIN EFFECT. Skin effect is negligible at low frequencies, but can be an important factor at high frequencies. Other contributing factors to inductor losses are (1) eddy currents set up in the core and surrounding objects (if they are conductors); (2) the dielectric properties of the form used for the coil and surrounding objects; and (3) hysteresis in the core and surrounding objects, if they are magnetic metals. Losses occur as a result of the dielectric properties of the coil form because of the distributed capacitance of the inductor (for example, between turns and between the terminals and leads). To some extent the core and surrounding objects serve as a dielectric of the distributed capacitance, and the resulting dielectric losses contribute to the overall losses of the inductor.

As we discussed earlier, an inductor has the ability to act as a storehouse of magnetic energy. However, because of the various loss factors described above, all of the energy stored in the magnetic field is not returned to the source when the applied voltage decreases to zero. The losses of an inductor may be represented by an equivalent series resistance. The value that it would dissipate would be an amount of energy equal to the total amount dissipated by the inductor. The losses of an inductor may be expressed in terms of the ratio of its inductive reactance to its equivalent series resistance. This ratio is referred to as the Q of the inductor and is stated in equation form as shown below:

$$Q = \frac{X_L}{R}$$

Q-14. What type of core produces the greatest inductance?

HAY BRIDGE

Inductance measurements are seldom required in the course of troubleshooting. However, in some cases inductance measurements are useful and instruments are available for making this test. Many capacitance test sets can be used to measure inductance. Most manufacturers of capacitance test sets furnish inductance conversion charts if the test equipment scale is not calibrated to read the value of inductance directly. For the measurement of inductance, the following basic types of test equipment circuitry are used: (1) the bridge-circuit type, which is the most accurate, and (2) the reactance type, which is often an additional test circuit incorporated into another piece of test equipment to increase its utility. The measurement of capacitance using the capacitance-inductance-resistance bridge instrument was discussed. Since the measurement of capacitance and inductance are interrelated, the existing capacitance standards and loss controls of this test equipment are used whenever possible. A wider range of dissipation must be provided to accommodate the practical value of inductors. The 250DE+1325 (view A of fig. 1-14), a typical rcl bridge and our reference in this discussion, uses two basic bridge circuits (Hay bridge and Maxwell bridge) to accommodate the extensive range in inductor loss factors. You should take time to review the bridges in NEETS, module 16, or other bridge-circuit descriptions before continuing.

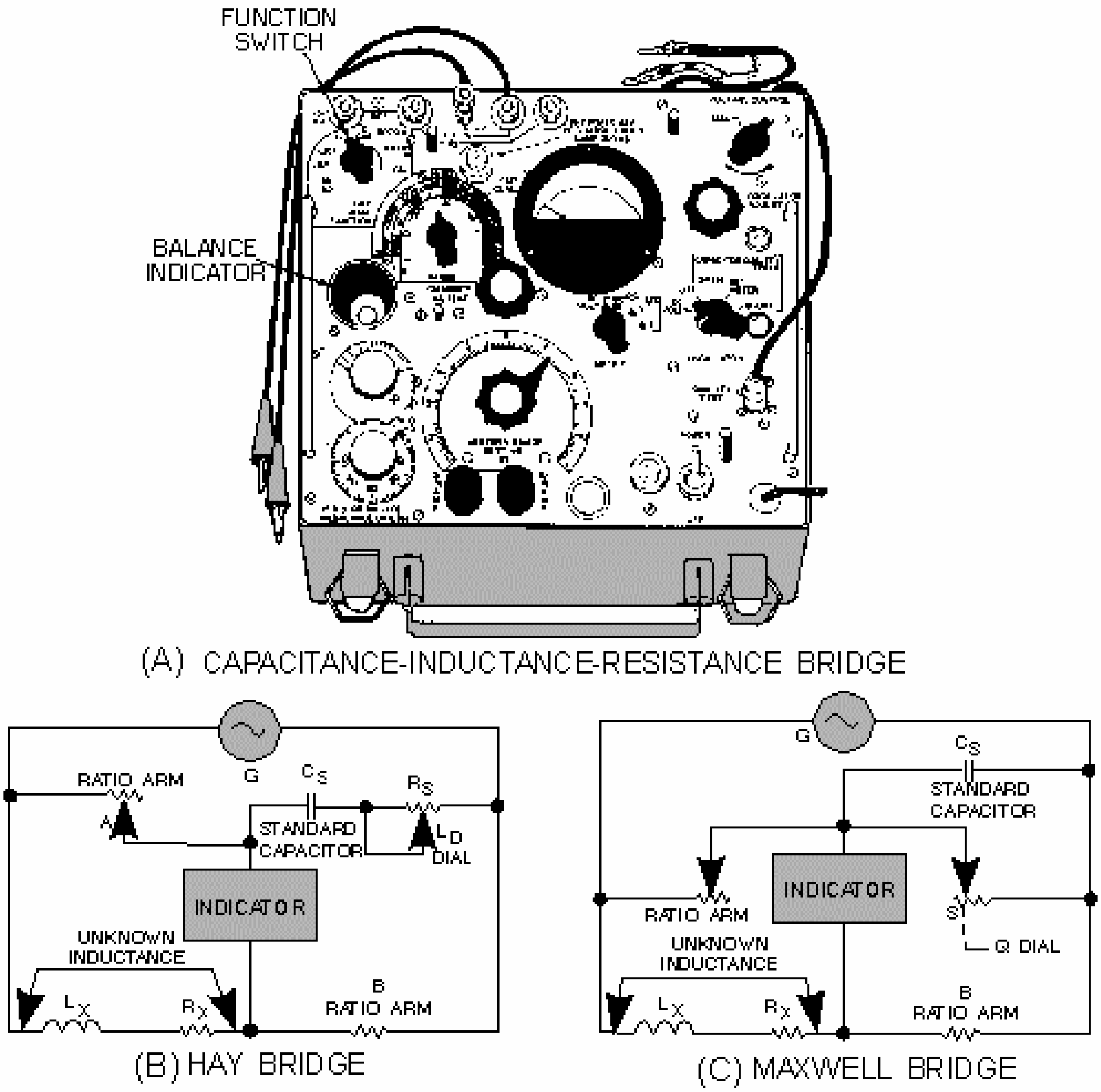


Figure 1-14.—Bridge circuits.

The Hay bridge (view B of fig. 1-14) measures inductance by comparing it with a capacitance; it differs from the Maxwell bridge (view C) in that the resistance associated with the capacitance is a series instead of a shunt resistance. The inductance balance depends upon the losses (*Q*) of the inductor. The Hay bridge is used for inductors with low losses low D dial reading or high *Q*) at 1 kilohertz. This circuit is in effect when the FUNCTION switch is turned to the L(D) position. For a D dial reading up to 0.05, the error is 0.25%. Above this point the error increases rapidly and affects the basic accuracy of the test equipment. This limitation is expressed on the front panel of the test equipment as follows: IF D>0.05 ON L(D)—REBALANCE ON L(Q) . In other words, if the dissipation of an inductor, as read on the D dial when using the Hay bridge (FUNCTION switch set to L(D) position), exceeds 0.05, then you should change to the Maxwell bridge (FUNCTION switch set to L(Q) position), which is discussed in the following paragraph. The loss factor of the inductor under test is then balanced in terms of the *Q* of the inductor.

Q-15. A Hay bridge measures inductance by comparing an inductor to what component?

MAXWELL BRIDGE

The Maxwell bridge, shown in view C of figure 1-14, measures inductance by comparing it with a capacitance and (effectively) two resistances.] This bridge circuit is employed for measuring inductances having losses greater than 0.05 (expressed by the D dial reading). For such inductors it is necessary to introduce, in place of the series control (D dial), a new loss control (Q dial), which shunts the standard capacitor. This control, which becomes effective when the FUNCTION switch is turned to the L(Q) position, is conveniently calibrated in values of Q, the storage factor of the inductor under measurement. The balance for inductance is the same for either bridge circuit. This permits the use of the same markings on the RANGE switch for both the L(D) and L(Q) positions of the FUNCTION switch.

REACTANCE MEASURING EQUIPMENT

The reactance type of inductance measuring equipment makes use of the following principle: If an ac voltage of fixed frequency is applied across an inductor (and a resistor in series), the voltage drop produced across the reactance of the inductor by the resulting current flow is directly proportional to the value of the inductance. An inductance measurement using the reactance method is identical to capacitance measurements using the same method, except that current flow is directly proportional to the value of inductance, rather than inversely proportional as in the case of capacitance. It follows then that if a reactance-type capacitance measuring equipment is provided with a chart that converts the capacitance readings to equivalent inductance values and a proper range multiplying factor, the same test setup can be used to measure both capacitance and inductance. In practice, test equipment using the reactance method for capacitance measurements usually provides an inductance conversion chart. Because the current flowing through the inductance under test is directly proportional to the value of inductance, the reciprocals of the capacitance range multipliers must be used; for example, a multiplier of 0.1 becomes

$$\frac{1}{0.1} \text{ or } 10$$

and a multiplier of 100 becomes

$$\frac{1}{100} \text{ or } 0.01$$

The reactance-type equipment gives approximate values only. Like the analog multimeter, it is used only when portability and speed are more important than precision. If the ohmic resistance of the inductor is low, the inductance value obtained from the conversion chart can be used directly. If the ohmic value (as measured with an ohmmeter) is appreciable, a more accurate value of inductance can be obtained by use of the following formula:

$$L = \frac{(Z_L)^2 - (R_L)^2}{2\pi f}$$

Where:

L = the inductance

Z_L = the impedance of the inductance under test

f = the frequency

R_L = the ohmic resistance

Q-16. Is the current flow through an inductor directly proportional or inversely proportional to its inductance value?

MEASUREMENT OF INDUCTANCE USING THE VTVM

If you do not have a 250DE+1325 at your disposal, the inductance of a coil can be determined by using a vtvm and a decade resistance box, as shown in figure 1-15. In the following example the inductance of an unknown coil in the secondary winding of a 6.3-volt filament transformer will be determined with a vtvm and decade resistance box. The unknown coil must be connected in series with the decade resistance box. The voltage across the decade box and across the coil must be monitored as the decade box is adjusted. When equal voltages are reached, read the resistance of the decade box. Since the voltage across the inductor equals the voltage across the decade box, the X_L of the coil must be equal to the resistance read on the decade box. For example, assume that the resistance reading on the decade box is 4 kilohms and the frequency is 60 hertz. This must mean that the X_L of the coil is also equal to 4,000 ohms. The inductance formula $L = X_L/2\pi f$ can be used to find the inductance of the coil in henries:

$$L = \frac{4000\Omega}{(6.28)(60)}$$

$$L = \frac{4000\Omega}{376.8}$$

$$L = 10.62H$$

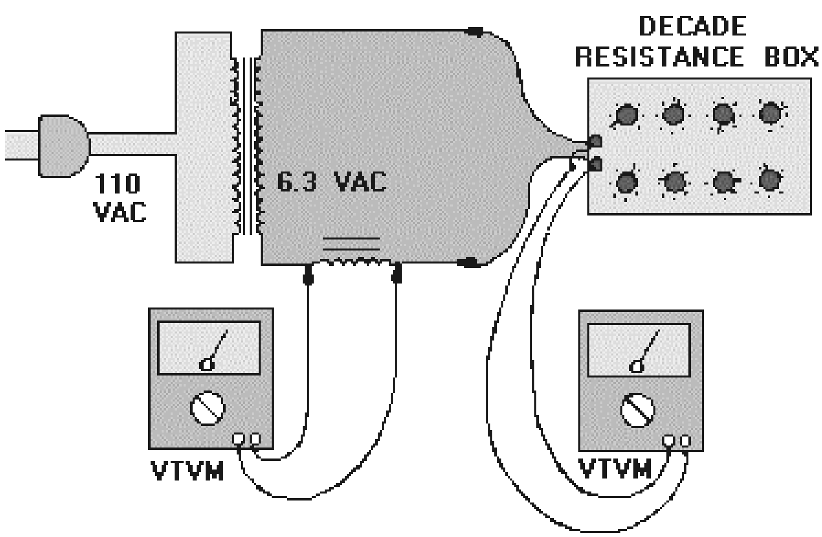


Figure 1-15.—Determining inductance with a vtvm and decade resistance box.

SUMMARY

This chapter has presented information on basic measurements. The information that follows summarizes the important points of this chapter.

The five basic measurements are **VOLTAGE, CURRENT, RESISTANCE, CAPACITANCE**, and **INDUCTANCE**. The accuracy of all measurements depends upon YOUR SKILL as a technician and the accuracy of your TEST EQUIPMENT.

Accuracy of different types of test equipment varies greatly and depends on design characteristics, tolerances of individual components, and YOUR KNOWLEDGE of test equipment applications.

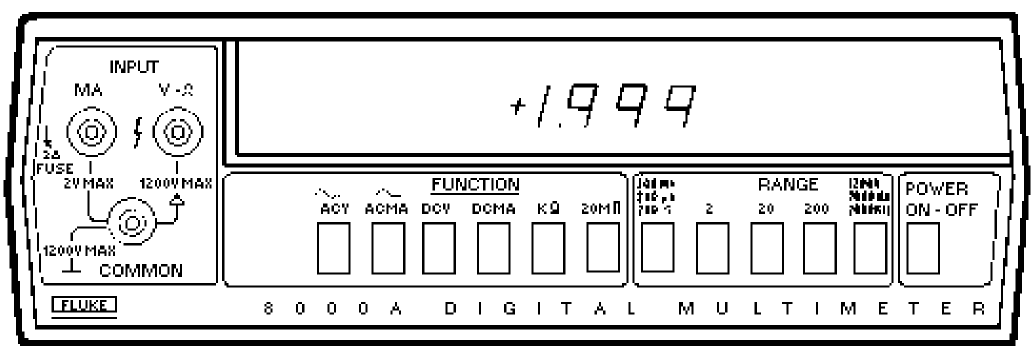
The **METCAL** program ensures that your calibrated test equipment meets established specifications.

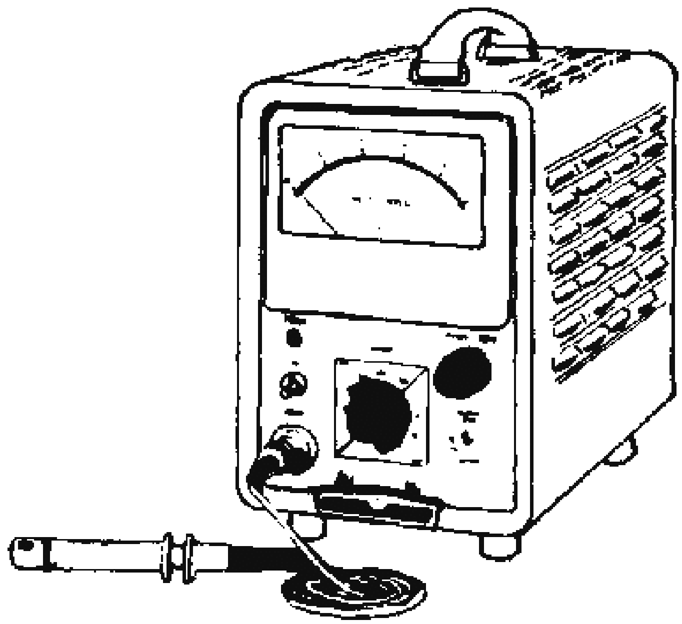
Most equipment technical manuals contain VOLTAGE CHARTS which list correct voltages that should be obtained at various test points.

It is important to remember that the **INPUT IMPEDANCE** of your test equipment must be high enough to prevent circuit loading.

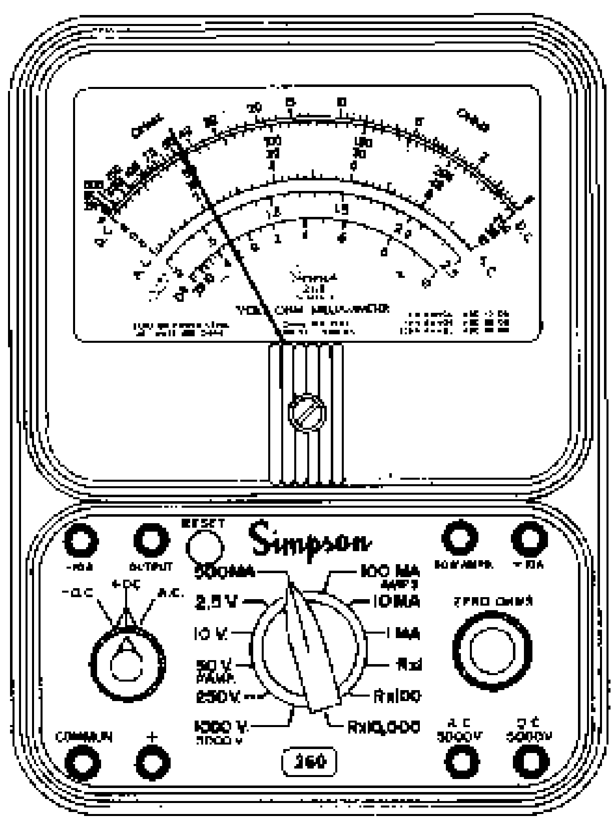
When you are performing ac voltage measurements, an additional consideration that greatly affects the accuracy of your measurements is the **FREQUENCY LIMITATIONS** of your test equipment.

Ac and dc CURRENT MEASUREMENTS can be performed using a wide variety of test equipment. Most current measurements require you to break the current path by unsoldering components and wires and inserting an ammeter in series with the current path. One alternative method is to compute (using OHM'S LAW) the current through a circuit by measuring the voltage drop across a known resistance. Another alternative is to use a CURRENT PROBE that requires no unsoldering.



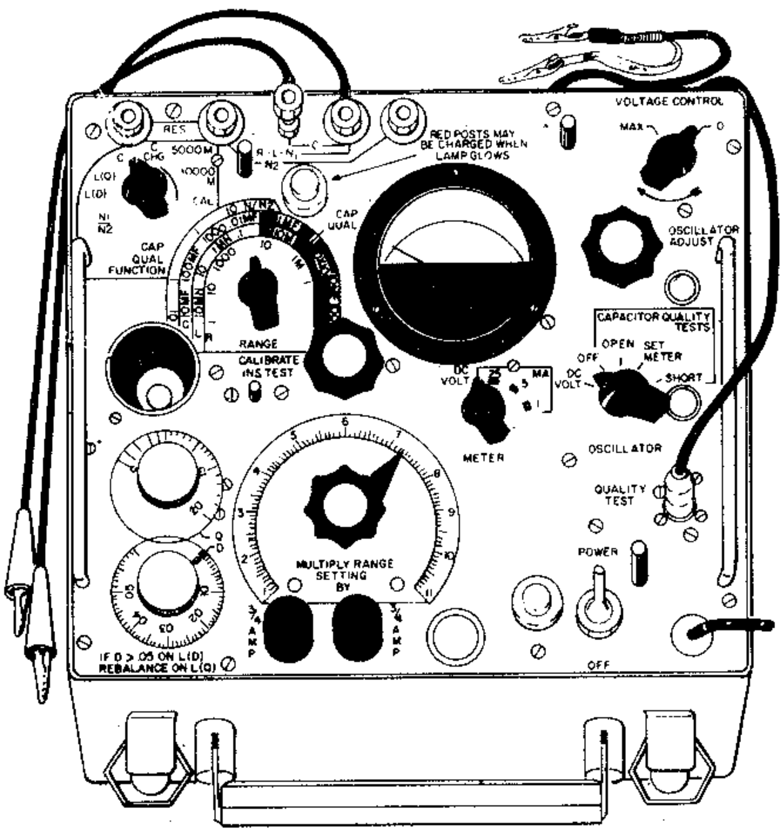


When performing resistance measurements, your primary concerns are the **RANGE AND DEGREE OF ACCURACY** of your test equipment. In most instances, an analog multimeter is accurate enough to perform basic troubleshooting. When measuring extremely large resistances, you are sometimes required to use a MEGGER or a DIFFERENTIAL VOLTMETER.



When testing current-sensitive devices, you must be certain that the current produced by your test equipment does not exceed the current limitations of the device being tested.

Capacitance and inductance measurements are seldom required in the course of troubleshooting. These measurements are usually performed with various types of BRIDGES or with a reactance type of measuring device. The bridge -measuring techniques are more commonly used and are more accurate than reactance types of measurements.



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ANSWERS TO QUESTIONS Q1. THROUGH Q16.

A-1. *Its calibration.*

A-2. *10 to 1*

A-3. *Increased input impedance, greater accuracy, and increased voltage range.*

A-4. *Midscale.*

A-5. *Accuracy and high input impedance.*

A-6. *The range of frequencies that can accurately be measured.*

A-7. *At least 60% of the vertical trace.*

A-8. *Decreased internal meter resistance, greater accuracy, and greater current range.*

A-9. *Current probes enable you to perform current measurements without disconnecting wires. Current probes are clamped around the insulated wire.*

A-10. *By zeroing the meter with the test leads shorted.*

A-11. *The current flow through the component is limited to 1 milliamp.*

A-12. *True.*

A-13. *Bridge type.*

A-14. *Magnetic-metal core.*

A-15. *A capacitor.*

A-16. *Directly proportional.*